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SKYLLAB EXPERIMENT
M566 COPPER-ALUMINUM EUTECTIC

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SUMMARY

The experimental hardware in Skylab flights 3 and 4 functioned satisfactorily to process three specimens in the low gravity of a Space environment. The multi-purpose Electric Furnace melted portions of three copper-aluminum specimens in each flight, held them at a soaking temperature, then re-solidified the molten portions at a controlled rate. Non-destructive evaluations including electrical resistivity, have been completed. Preliminary data from quantitative metallography indicate that the aligned eutectic in specimens processed in Skylab 3 and 4 have fewer defects than ground-based specimens, specifically an improvement of 12% in average defect spacing and a decrease of 20% in the average fault density.

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INTRODUCTION

Directionally solidified eutectics as prepared in a one-g environment, almost always exhibit termination faults, mismatch surfaces and other defects. These growth imperfections limit their strength when used as structural composites and prevent their use for non-structural applications such as Micro Capacitors. The formation of a mismatch surface in an aligned eutectic involves an increase in net surface area. [1] The appearance of terminations allows lamellae to maintain their parallel growth but there is no compensation for the excess surface and increased energy at the mismatch surfaces. Because of the incomplete explanation for occurrence of all such defects in lamellar eutectics, it appeared reasonable [2] that an experiment in the orbiting Skylab would show that an improved structure could be grown in the absence of gravity induced thermal convection. The growth of a eutectic composite of aligned lamellae in low gravity should also provide new insights into the parameters affecting their solidification. The $CuAl_2$ eutectic (67% Wgt Aluminum-33% Wgt Copper) was selected as a model system on the basis of its moderate eutectic temperature and the extensive background of solidification information available with which zero-g results may be compared.

This paper will describe the hardware and results of our non-destructive evaluation and quantitative metallography.

Experimental Description

Specimens and Hardware Design

Single-grained specimens for this experiment were prepared by directional solidification. The initial castings were made from master heats of zone-refined aluminum and spectrographic copper. [3]

The design of the M566 cartridge is similar to others used in the M518 Multipurpose Electric Furnace. [4] The copper-aluminum eutectic specimen is 6.25 mm in diameter and 12.7 mm in length.

The cartridge assembly for each specimen was designed so that the molten eutectic alloy would contact graphite only. The following heating and cooling parameters were selected for ground-based tests and the Skylab experiment:

Peak Temperature - 867°C in the heated portion of furnace
- 790°C in the specimen
Soak Time at Peak Temperature - 1 hour
Solidification Rate - 2.4°C/min.
Average Thermal Gradient - 45°C/cm.

Due to a malfunction of the control thermocouple in the furnace in Skylab 3, the peak temperature did not exceed 844°C.

Three additional specimens were processed in Skylab 4, at the desired temperature of 867°C.

Results of Non-destructive Evaluation

Photography and Radiography

Each specimen from Skylab 3 shows a reduced diameter or hour glass shape in the regrowth region (Fig. 1). This hour glass shape was not present on ground based specimens. The cause of this reduction in diameter is not exactly known but is considered to be due to a combination of instability of the column of molten metal and surface tension restraints during solidification. Specimens from Skylab 4 had very slight diameter reduction only.

Resistivity

Electrical resistivity in directionally solidified specimens of aluminum-$CuAl_2$ eutectic is anisotropic. [5] The expected range of variations of resistivity as a function of orientation angle is shown in Fig. 2. When aligned lamellae are parallel to the direction of resistivity measurement, (Θ of 90°), resistivity will vary from 3.78 to 4.04 micro ohm-centimeter. When lamellae are perpendicular to the direction of resistivity measurement, (Θ of 0°) resistivity will vary from 4.47 to 4.60 micro ohm-centimeter. Conventional techniques for measuring resistivity were not sufficiently accurate. Resistivity therefore was measured by a new technique using decay of eddy currents. Variations of resistivity values measured locally on a ground-based specimen and a Skylab 4 specimen are shown in Fig. 3. The resistivities at the hot ends of both specimens are comparable. Resistivities measured at the remelt interfaces of both specimens are also comparable. The increase in resistivity near the surface deformity is considered to be due to disruption of the aligned lamellae near this portion.

Quantitative Metallography

The lamellar width (λ) is the spacing for one pair of lamellae, expressed in microns or micro-meters. (Fig. 4)

The fault density (N_A) is the number of terminations and other defects such as kinks in an area of $(100\,\lambda)^2$. The average length of mismatch line is normalized for an area of $(100\,\lambda)^2$ and is expressed in $Cm/(100\,\lambda)^2$. The average defect spacing between mismatch lines is expressed in lamellar widths.

Results and Discussion

As shown in Fig. 5, the fault density [6] or the number of terminations and defects for a standard area in the Skylab 4 specimen is 20% fewer than the ground based specimens. The Skylab 3 specimen has a much higher fault density than either the ground-based or Skylab 4 specimen because of the surface irregularities and dis-orientation of the microstructure.

As shown in Fig. 6, the differences in average length of mismatch lines [6] and [7] are very slight. Again, one of the Skylab 3 specimens is much worse than ground-based specimens.

As shown in Fig. 7, the average defect spacing favors the Skylab 4 specimens. Please note that the data from Georgia Tech [7] shows their S/L 4 specimen to be best, while the University of Connecticut data [6] show their S/L 4 specimen to be the best. Some variation in counting techniques of such complex micro structures should be expected. In each instance the advantage is 12 to 13% for the S/L 4 specimen.

Figures 8, 9 and 10 show transverse sections of a typical ground-based specimen and Skylab processed specimens at similar distances from the remelt interface. A study of them will confirm that the Skylab 4 specimen has larger areas free from defects and therefore fewer defects. The magnification is approximately 500X on each but is varied slightly to facilitate visual comparison over normalized areas of $(100\,\lambda)^2$.

CONCLUSION

Quantitative metallography shows that specimens processed in the zero gravity of S/L 4 are superior to ground-based specimens on two characteristics:

The defect spacing in lamellar widths is 12% better.
The fault density is 20% less.

REFERENCES

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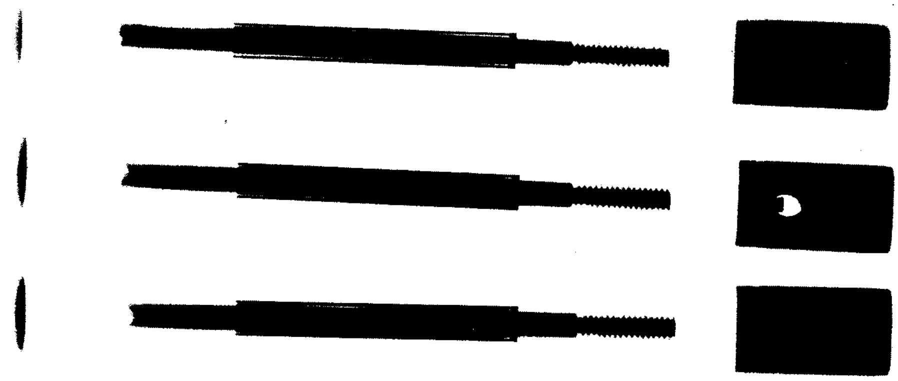

FIGURE 1. RADIOGRAPH OF COPPER-ALUMINUM EUTECTIC SPECIMENS IN CARTRIDGES FROM SKYLAB 4.

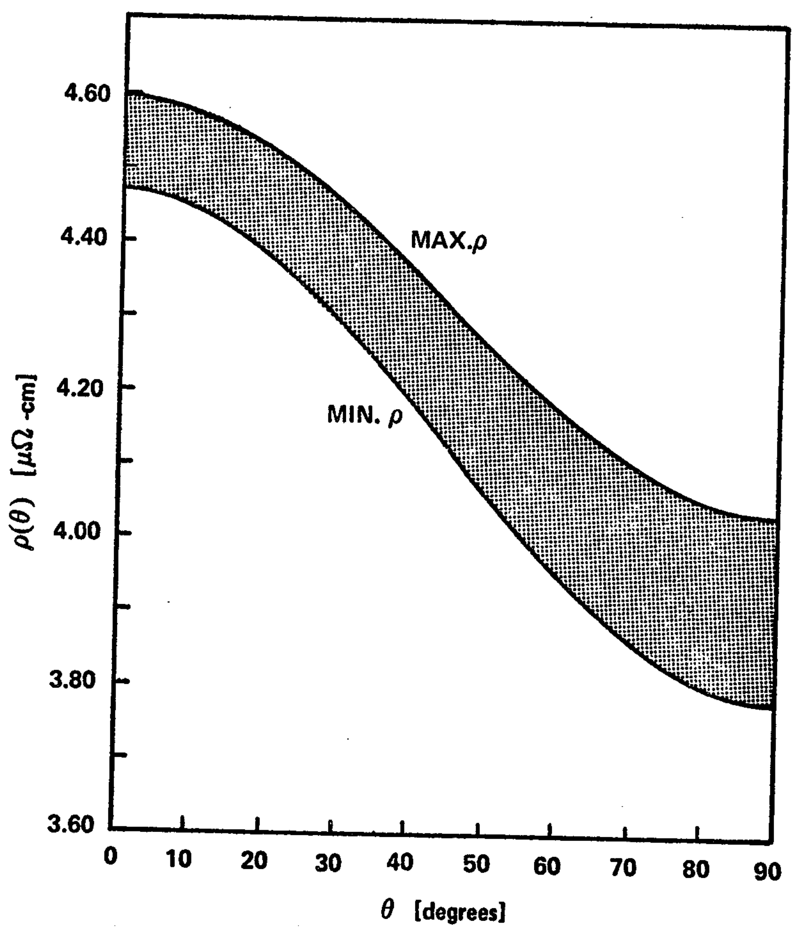

FIGURE 2. THE MAXIMUM AND MINIMUM VALUES OF ELECTRICAL RESISTIVITY FOR DIRECTIONALLY SOLIDIFIED Al-Cu EUTECTIC AS A FUNCTION OF ORIENTATION ANGLE.

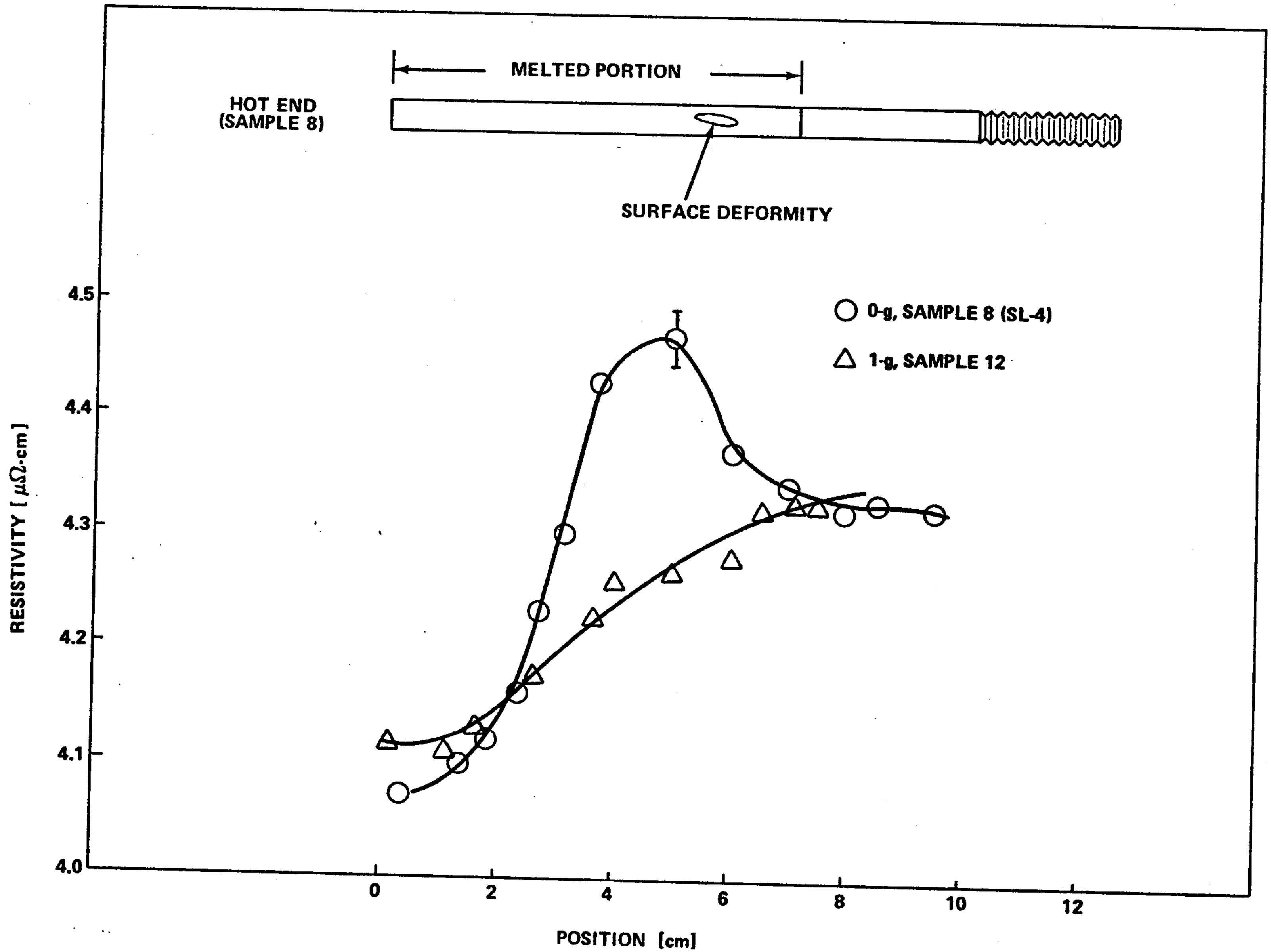

FIGURE 3. LOCAL RESISTIVITY OF SAMPLES M566-8 AND M566-12 [5]

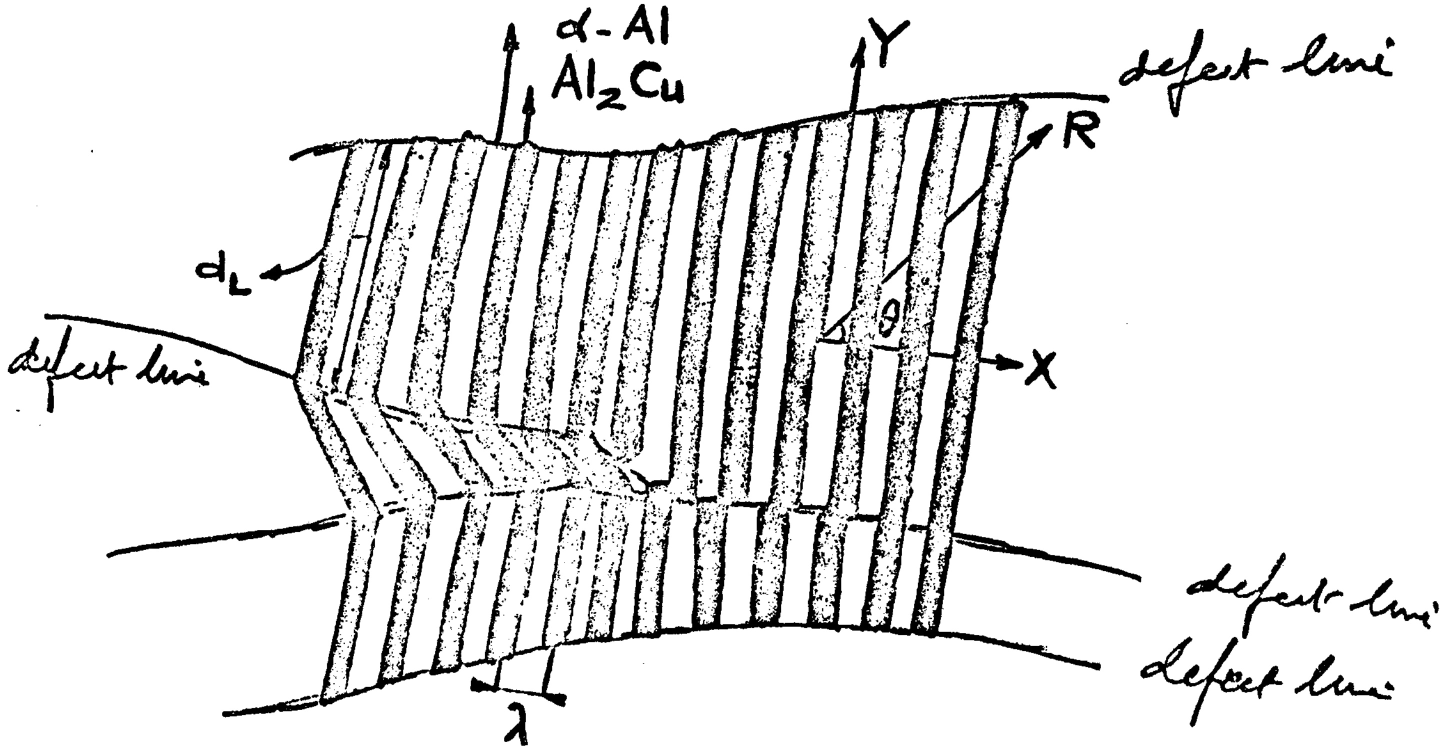

FIGURE 4. SCHEMATIC REPRESENTATION OF A TRANSVERSE SECTION IN DIRECTIONALLY SOLIDIFIED Aℓ-Cu EUTECTIC ALLOY [6]

QUANTITATIVE METALLOGRAPHY

SPECIMEN	NUMBER OF TERMINATIONS AND DEFECTS IN ($100 \lambda^2$) AREA
M566-7 S/L 4	925
M566-11 GROUND	1150
M566-15 GROUND	1150
M566-5 S/L 3	2000

FIGURE 5. M566 COPPER-ALUMINUM EUTECTIC

QUANTITATIVE METALLOGRAPHY

SPECIMEN	AVERAGE LENGTH OF MISMATCH LINE, (CM/$(100\lambda)^2$
M566-15 GROUND	0.364 (C)
M566-7 S/L 4	0.380 (C)
M566-9 S/L 4	0.540 (T)
M566-11 GROUND	0.550 (C)
M566-6 S/L 3	0.584 (T)
M566-10 GROUND	0.668 (T)
M566-5 S/L 3	0.935 (C)

FIGURE 6. M566 COPPER-ALUMINUM EUTECTIC